Functional Objectives for Stream Restoration

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September 2006

Complexity	Value as Planning Tool	Cost
Low Moderate High	Low Moderate High	Low Moderate High

OVERVIEW

The National Research Council (1996) defined restoration as "the return of the form and function of an ecosystem to its pre-disturbance condition…" This definition presents two challenges when working in today's environment.

First, the significant hydrological changes and infrastructure encroachments found in many watersheds often prevent the reestablishment of the stream form to a condition prior to disturbance. These streams have a new form consistent with the altered conditions, and may not be able to maintain functions associated with a pre-disturbance condition.

Second, while the general concept of "functions" can be grasped by most, the specific functions provided by streams and riparian corridors have yet to be defined in a manner that can serve as a basis for assessment, design, and management.

The recommendations presented in this document center on the recognition that the character of stream systems (and, thus, their value or potential to support certain uses) is a result of a set of dynamic and interrelated processes referred to as functions in this report. Fifteen critical functions were identified by a committee of U.S. and international scientists, engineers, and practitioners, and were synthesized into a framework for ecosystem evaluation.

Understanding the basic functions of streams and riparian corridors provides planners and designers with a concise and effective basis from which to evaluate proposed projects, and offers several powerful advantages over assessments that focus upon beneficial uses. Use of functions and processes can be elegantly incorporated within a systems approach, enhancing understanding, enabling predictions, and supporting management decisions.

This report presents the functional framework and discusses ways in which the framework can be applied to support the Corps' Ecosystem Restoration and Urban Flood Damage Reduction Programs.

Figure 1. Healthy streams and riparian zones support important functions, even if their form has been altered from historic conditions.

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
SEP 2006	**N/A**	**-**

4. TITLE AND SUBTITLE	
Functional Objectives for Stream Restoration	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Engineering Research and Development Center Vicksburg, MS 39180**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**18**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

FUNCTIONAL FRAMEWORK

Watersheds are often viewed in terms of the uses they support. This viewpoint stems from the philosophy that all watersheds can provide certain uses within limits. Current concepts of sustainability - i.e. “meeting the needs of current generations without compromising the needs of future generations” - center on this notion (United Nations 1992). Beneficial uses and values, however, are not consistent across political boundaries, change with public perception and with time, and are difficult or impossible to measure (Brinson 1993, Brinson et al. 1995). Objective decisions regarding the implications of proposed ecosystem alterations thus require consideration of factors beyond an assessment of the potential impacts to users.

Although watershed characteristics vary from one area to another and over time, all watersheds support common physical, chemical, and biological processes that interact to form and maintain streams and riparian areas. These processes, and certain characteristics of the ecosystems, can be termed ecological functions. The functional viewpoint evolves from the recognition that watersheds support ecosystem components that interact in complex ways to contribute to the continual restructuring of the watershed and its associated elements and features. This is a dynamic, variability-based concept.

A shift within the scientific community is underway in which a functional approach (rather than a beneficial use approach) is being advocated for stream restoration planning and design because this approach:

a. Has a scientific basis, and can be measured using established ecological and physical methods. This scientific basis is compared to beneficial use assessments, which are based on public perceptions and politics, and, unlike functions, can change with public perception or political entities.

b. Is based on processes and interactions and is capable of targeting the cause of impairment within a watershed, providing a sound basis to evaluate projects at the initial purpose and need level.

c. Can identify similarities and dissimilarities among stream reaches, watersheds, and stream classes in order to establish reference conditions, prioritize watersheds for preservation or restoration, document and account for scale issues, and reduce error associated with natural variation in aquatic ecosystems.

d. Strengthens the prediction and quantification of short- and long-term effects on ecosystem quality and quantity, the determination of appropriate restoration that restores functionality, and identification of success criteria.

e. Permits the aggregation of process alterations to assess cumulative impacts, and fosters the evaluation of ecosystem interdependencies.

f. Has the unique ability to address impairment caused by maximum loading and can be used to identify thresholds.

g. Can be used to formulate hypotheses and identify research needs if it is based on direct measures and surrogates of those measures.

Assessments based on beneficial uses do not offer these powerful capabilities.

The primary advantage of this functional systems approach is that it permits the rapid identification of practicable alternatives and the assessment of potential impacts from each. At the same time, the functional approach expands perspective from 1) a species to an ecosystem level, 2) considering a specific site to the role of the site within the broader watershed, and 3) focusing on end products to focusing on the processes that created them. Viewing watersheds in terms of beneficial uses can result in unclear and often conflicting planning and management direction. Conversely, viewing them in terms of the functions they support can allow for a clear, consistent assessment of status and effects. This paper proposes the use of a functional framework as a basis for assessing watershed conditions and likely responses to management activities.

Function Categories

Healthy streams support and maintain basic functions associated with either structure or processes that result in a continual development or evolution of the watershed. These functions relate to the physical, biological, and chemical nature of waterways but do not relate directly to their social context, which is addressed later in the category of beneficial uses. The basic functions that streams and riparian corridors support can be divided into five categories:

- System dynamics.
- Hydrologic balance.
- Sediment processes and character.
- Biological support.
- Chemical processes and landscape pathways.

Within each of these categories, three key functions, components and processes (Table 1) were compiled from a preliminary list of over 60 functions identified by a scientific committee. The committee was well aware of the interconnection, interdependence, and integration of functionality expressed in aquatic ecosystems. To reduce bias, this technical note discusses each function independently. An attempt is then made to recouple the interdependence of functions. It is important to note also that not all functions will be of equal importance in individual watersheds, so interpretation of this framework will be required for each situation.

Tables 2 through 6 present an overview of each of the 15 primary functions. This overview is supported and augmented by the references provided in the bibliography at the end of this technical note, and is expanded upon in another document (Fischenich 2003).

Generally speaking, an individual will be knowledgeable about only a few of these functions, but the team involved in planning and design for the project should be comprised of individuals that collectively possess expertise in all the functional categories. Understanding ecosystem functions will help planners and designers formulate alternatives and assess the relative benefits and impacts of each. To help with this need, Tables 2 through 6 present lists of indicators commonly used to determine the presence/absence of a particular function, as well as lists of measures used to quantify the degree to which the functions are present.

Table 1. Summary of Primary Functions.

System Dynamics	Hydrologic Balance	Sediment Processes and Character	Biological Support	Chemical Processes and Pathways
Stream Evolution Processes	Surface Water Storage Processes	Sediment Continuity	Biological Communities and Processes	Water and Soil Quality
Energy Management	Surface / Subsurface Water Exchange	Substrate and Structural Processes	Necessary Habitats for all Life Cycles	Chemical Processes and Nutrient Cycles
Riparian Succession	Hydrodynamic Character	Quality and Quantity of Sediments	Trophic Structures and Processes	Landscape Pathways

Indicators and Measures of Functions

There is consensus that the world's streams and riparian corridors are of fundamental importance to human health, that they are increasingly threatened by economic change and by environmental degradation, and that, consequentially, urgent and effective attention is needed. To provide this, it is important to assess accurately the current state of these aquatic and semi-aquatic systems, through the indicators and measurements provided, and to predict system trends inclusive of the consequences of various management alternatives. Addressing these needs requires both qualitative and quantitative approaches, through which the sustainability of relevant systems can be assessed and sometimes measured.

Indicators are variables, features or attributes that allow for a reasonable and practical means of identifying the presence or absence of a particular function. They also serve to foster an understanding of cause/response relations at and between the various scales present on aquatic systems - not a simple matter given the complexity of ecosystems. Processes operate across scales and thus define critical linkages (e.g. runoff generation, sediment load and transport, erosion/deposition, and plant interaction/succession). These processes are assessed in terms of the physical variables, features and attributes that are manifest at the scales of watershed, reach and site. Indicators are generally qualitative, though they can be semi-quantitative as well.

Measurement of certain attributes allows quantification of the degree to which a particular function is achieved in an ecosystem. Measures can be physical, ecological, economic, or social. Indicators and measures for the primary functions identified in the previous section are summarized in Tables 2 through 6.

Beneficial Uses Perspective

The social aspects of stream and riparian ecosystems are addressed in this report as beneficial uses. Uses are classified as a sink, a source (consumptive use), or indifferent (non-consumptive). Table 7 lists common uses of rivers and riparian corridors and how they affect or are affected by the function categories. Beneficial uses are presented without regard for priority or value, which varies with time and by region.

Table 7 demonstrates the considerable interrelation between the functions and the common beneficial uses ascribed to the resource. A particular use can impact one or more functions, with consequent impacts upon other potential uses. Uses are not consistent across political boundaries, change with public perception or time, and are difficult or impossible to measure, but the fundamental processes (i.e. functions) that support them are less susceptible to these variations and difficulties.

Many of the functions are interrelated such that impacts to one function can cause a cascade of impacts to other functions and to multiple uses. For example, actions that impact the surface/subsurface exchange of water will almost certainly impact the stream's hydrodynamic character, riparian succession, water quality, and habitat. Depending upon the nature and magnitude of the impact, surface water storage, chemical processes, biological communities and trophic structure might also be impacted, but the other functions are likely to remain largely unaffected.

Establishing a hierarchy of functions is difficult because no single function is unaffected by the others. The relative significance of each function can be inferred by assessing the interrelations among functions. The results of such an assessment are presented in Table 8. In this regard, the hydrodynamic character of the system may be the most significant of the functions as it directly or indirectly affects all other functions.

Habitat – the focus of most restoration efforts – is the lowest ranked function in this analysis because it affects only three other functions, suggesting that the remaining functions are relatively insensitive to habitat changes. On the other hand, habitat is directly influenced by all but three of the other functions. This implies that habitat may be a good indicator of an impacted system, but impacts to habitat may provide little insight into the causal mechanism of the disturbance.

Table 2. System Dynamics.

Function	Description	Indicators	Measurements
Maintain stream evolution processes	➢ Necessary process to maintain appropriate energy levels in the system. ➢ Promotes normally occurring change necessary to maintain diversity and succession. ➢ Provides for genetic variability and species diversity of biotic communities.	Systemic changes to channel cross-section, planform, or grade. Magnitude, frequency, and duration of flow changes. Bed armoring or sorting. Evidence of bed erosion or deposition. Bank erosion. Diverse riparian vegetation and aquatic biota. Presence of pioneer vegetation species. Stream stability. Changes in the composition of the aquatic community.	Stability assessment techniques that quantify bed and bank stability. Channel evolution model stage and change. Rates of change of channel geometry parameters. Time-series aerial photo analysis of stream pattern. Quantity, densities, ages, types, % cover of different vegetation. Abundance and distribution of pioneer species, as well as rate of succession. Flood history polygons (exceedance intervals). Other disturbance process measures (e.g., fire).
Energy management processes	➢ Spatial and temporal variability in cross section, grade, and resistance allows for conversion between potential energy and kinetic energy through changes in physical features, hydraulic characteristics, and sediment transport processes. ➢ Provides habitat, generates heat, oxygenates flows.	Changes in physical stream features, such as width, depth, slope, and bed and/or bank roughness. Changes in flow state or condition. Erosion/deposition pattern change. Alternate and diverse reach classifications (riffle, pool, run). Watershed disturbance patterns. Changes in terrestrial and aquatic biota.	Determine energy grade line and hydraulic grade line and compare with bed slope at different flows. Quantify variability in physical stream features or hydraulic features along the channel and compare to reference channels. Measure channel/floodplain constrictions.
Provide for riparian succession	➢ Changes in vegetation structure and age promote diversity and ecological vigor by initiating change, which is important to long-term adaptation of ecosystems. ➢ Zones of mature riparian vegetation are necessary for system stability, LWD recruitment, and nutrient cycling.	Presence of pioneer species. Diversity of vegetation. Varied age classes. New sediment deposition and active erosion.	Measures of species diversity, composition, age, and structure. Riparian zone width. Seedling distribution. LWD recruitment rate.

Table 3. Hydrologic Balance.

Function	Description	Indicators	Measurements
Surface water storage processes	➢ Provides temporary water storage during high flows. ➢ Regulates discharge and replenishes soil moisture. ➢ Provides pathways for fish and macroinvertebrate movement. ➢ Provides low-velocity habitats. ➢ Maintains base flow and soil moisture. ➢ Provides contact time for bio-geochemical processes.	Presence of perennial flood-plain topographic features, such as floodplain lakes, ponds, oxbows, wetlands, and sloughs. Riparian wetlands, depres-sions, and microtopog-raphic changes in active floodplain. Presence of floodplain-spawning fishes. Presence of macroinvertebrate and amphibian indicator species. Watershed % impervious surface. Riparian debris patterns. Detrital accumulations.	Backwater computations. Hydrologic routing models. Stream entrenchment surveys. Rating curves. Floodplain species spawning success. Topographic surveys. Infiltration rates, com-paction surveys. Gage and well records.
Maintain surface / subsurface water connections and processes	➢ Provides bi-directional flow pathways from open channel to subsurface soils. ➢ Allows exchange of chemicals, nutrients, and water. ➢ Moderates low and high in-channel flows. ➢ Provides habitat and pathways for organisms. ➢ Maintains subsurface capacity to store water for long durations. ➢ Maintains base flow, seasonal flow, and soil moisture.	Invertebrates found in the hyporheic zone under floodplains. Presence of floodplain topographic features that connect the channel to groundwater recharge areas by free-draining soils. Occurrence of flows sufficient to allow connection. Presence of layers of silt or organics in soil profile. Moist soil conditions, hydro-phytic vegetation. Adjacent wetlands, hydric soil indicators. Groundwater elevation fluctuations. Watershed % impervious surface.	Flux in groundwater levels. Stream baseflow. Hyporheic macroinver-tebrate distribution, density, and diversity. Complexity of microtopography. Isotope dating. Soil porosity. Water chemistry profiles. Temperature recording. Texture, structure, moisture, redox, and porosity of adjacent soils.
General hydro-dynamic balance	➢ Rivers have a unique hydrologic signature important in ensuring proper flow conditions at the appropriate seasons for support of the biotic environment.	Presence of an active floodplain. Associated wetlands. Redoximorphic features and other indicators of hydric soils. Hydrophytic vegetation, drift line, and sediment deposits at appropriate elevations.	Flow duration analyses. Rating curves. Spawning success.

Table 4. Sediment Processes and Character.

Function	Description	Indicators	Measurements
Sediment continuity	➢ Provides for appropriate erosion, transport, and deposition processes. ➢ Maintains substrate sorting and armoring capabilities. ➢ Provides for the establishment and succession of aquatic and riparian habitats. ➢ Important part of nutrient cycling and water quality maintenance.	Bed sediment character. Evidence of recent channel or floodplain sediment and detrital deposits. Recent bed or bank erosion. Channel planform, section, or grade changes. Active bars. Changes in supply, erosion and deposition patterns. Diversity in aquatic and riparian biota. Watershed disturbance patterns. Composition and diversity of macroinvertebrates. Changes in magnitude, duration, or frequency of flow.	Bed material sediment loads and gradations. Suspended sediment load assessments. Stability assessment techniques. Temporal changes in channel geometry. Sediment yield measures. Sediment transport modeling and/or incipient motion analysis. Lower bank angle surveys. Stream bed core sampling.
Maintain substrates and structural processes	➢ Stream channels and riparian zones provide substrates and structural architecture to support diverse habitats and biotic communities. ➢ Complex habitats naturally attenuate the effects of irregular disturbance processes such as fire and floods.	Presence and health of indigenous biota. Distribution, abundance, health and diversity of biota. Relative complexity of substrates. Structural complexity and distribution. Abundance and distribution of large woody debris. Habitat diversity and complexity. Population trends of indicator species. Disturbance history.	Presence, composition, frequency, and distribution of physical characteristics such as pools, riffles, bedforms, specific depths and velocities, cover and substrate features, riparian corridor widths, etc. Aquatic and riparian habitat assessment methods such as PHABSIM, RCHARC, RBPS, HEP, IBIs. Distribution and frequency of key physical parameters. Riparian and in-channel woody debris surveys. Aquatic macrophyte surveys. Periphyton samples. Stream substrate composition. Soil compaction, displacement, or erosion. Detrital mass surveys. Bacterial counts. Fungal surveys. Fire and flood history mapping.
Quality and quantity of sediments	➢ Organisms often evolve under specific sediment regimes and these must be preserved for the ecological health of the system. ➢ Sediment yield and character are primary variables in determining the physical character of the system.	Change in banks, pools, and bars acceptable relative to other similar streams. Distribution, abundance, health, and diversity of biota. Presence of indicator species.	Sediment grain size distribution. Embeddedness. Sediment yield. Bedload. Suspended sediment load. Sediment concentration. Secchi depth. Armor layer size and thickness. Depth to bedrock. Sediment mineralogy. Macroinvertebrate surveys. Redd counts.

Table 5. Biological Support.

Functions	Description	Indicators	Measurements
Support biological communities and processes	➢ Provides for diverse assemblages of native species. ➢ Maintains natural predator/prey relationships. ➢ Maintains healthy physiological conditions of biotic communities. ➢ Maintains genetic diversity. ➢ Maintains age class and life form structures. ➢ Provides for natural reproduction and long-term biotic persistence.	Changes in population trends. Changes in health or condition of individuals or populations. Abnormal behaviors. Unbalanced predator/prey communities. Changes in growth or reproduction. Unbalanced age class or life form structures. Unusual species occurrence outside of normal ranges or preferred habitats. Presence of non-native species. Hybridization.	Population and individual growth rates and condition factors. Disease histories, bacterial and viral profiles. Species diversity and other IBIs. Species assemblages relative to reference conditions. Viability analyses. Population surveys, including density, age-class structure, life-form composition, etc. Bioassays. Stomach content analyses. Genetic testing and mapping. Species distribution relative to reference.
Provide necessary aquatic and riparian habitats	➢ Produces and sustains habitats to support vigorous aquatic and riparian biotic communities. ➢ Provides for basic food, air, light, water and shelter needs of dependant species. ➢ Provides habitats suitable for reproduction. ➢ Supports migration and staging areas. ➢ Provides key temporal habitats during periods of population stress.	Presence/absence/complexity of habitat features. Presence/absence/health of key indicator species, and native, non-native, surrogate, or invasive species. Observations of surrogate signs: remains, nests, dens, trails, feces, fur, prints, etc. Evidence of predator/ prey or reproductive, cooperative, or social behaviors. Presence of critical microhabitat features. Distribution, diversity, and quality of habitats throughout species ranges and over time. Secure recruitment pathways. Disease, extreme population fluctuations.	Measures from Rapid Stream Assessment Procedure, or other habitat modeling such as RCHARC, PHABSIM, HEP. Comparison of biotic counts to reference Indices of Biotic Integrity (IBI). Composition, structure, extent, variability, diversity, abundance of habitat features, key indicator species, native, non-native, surrogate, or invasive species relative to reference conditions. Habitat suitability, complexity, and diversity measures/models. Limiting habitat factor surveys. Refugia network mapping. Terrestrial and aquatic temperature studies. Corridor connectivity assessment. Habitat fragmentation surveys.
Maintain trophic structure and processes	➢ Promotes growth and reproduction of biotic communities across trophic scales. ➢ Maintains contact time for biotic and abiotic energy processes. ➢ Maintains equilibrium between primary autotrophs and primary microbial heterotrophs. ➢ Supports food chain dynamics to convert energy to biomass. ➢ Supports characteristic patterns of energy cascade and pooling. ➢ Provides nutrient levels capable of sustaining indigenous biologic communities.	Presence/ absence of producers and consumers. Evidence of periphyton growth on substrate. Evidence of detrital shredding and decomposition. Presence/absence of a balance and variety of nutrients and organisms to convert carbon, nitrogen, and/or phosphorus between forms. Presence/absence/abundance of snags, previous season's plants, leaf litter, detritus. Evidence of detrital shredding and decomposition. Organic horizon and organic layers in soil. Presence/absence/abundance of native, non-native, and invasive indicator species.	Aquatic and riparian vegetation density. Periphyton biovolume. Density, composition, and biomass of invertebrate consumers, diversity indices, and other IBIs. Measure of N:P ratios in water. Diversity and composition of stream biota. Measure of primary productivity. Measure of detritus production, CPOM, FPOM, DOM. Measure of large woody debris frequency and density. Comparison of above- and below-ground biomass R/S ratio. Biomass production of stream-dependant species. Biomass profile.

Table 6. Chemical Processes and Pathways.

FUNCTIONS	Description	Indicators	Measurements
Maintain water and soil quality	➢ Water quality parameters are directly tied to support of biologic community. ➢ Riparian communities trap, retain, and remove particulate and dissolved constituents of surface and overland flow, improving water quality. ➢ Regulates chemical and nutrient cycles. ➢ Controls pathogens and viruses. ➢ Maintains chemistry and equilibrium conducive to reproduction, behavior, development and sustainability of a diverse aquatic ecosystem. ➢ Supports important chemical processes and nutrient cycles.	Watershed conditions and disturbance features. Stream order. Presence/absence/abundance of key indicator biota. Presence/absence of trophic indicators. Abnormal forms or behaviors; unusual mortalities of indicator species. Plant, fish, and invertebrate density, diversity, distribution, and health. Wetland and riparian aerial and positional changes. Geology and soils - availability of a range of surface textures and areas for reactions. Presence/ absence of riparian sediment deposits. Density, diversity, and distribution of microbial, fungal, and invertebrate communities.	Conventional water quality measures (e.g., D.O., pH, conductivity, turbidity, TDS, salinity, temperature, suspended sediment). Bacterial counts. Metals and trace element sampling. Nutrient (N, P) tests. Examination of soil profiles. Soil profile elemental composition surveys. Rates of sediment deposition in channel and riparian corridor. Detrital mass surveys. Large woody debris counts. Infiltration rates. Compaction, displacement, and erosion surveys. Bacterial counts. Trace element sampling. Nutrient (N, P) tests. COM levels.
Maintain chemical processes and nutrient cycles	➢ Provides for complex chemical reactions to maintain equilibrium and supply required elements to biota. ➢ Provides for acquisition, breakdown, storage, conversion, and transformation of nutrients within recurrent patterns.	Presence of seasonal debris in riparian area. Presence/ absence of indicator species and their health. Presence/absence of photosynthesis, fecal matter, biofilms, and decomposition products. Presence/absence of particulates on vegetation. Riparian vegetation composition and vigor. Changes in algae, periphyton, or macrophyte communities. Changes in trophic indicators.	BOD (CBOD & NBOD) and DOC. Stable carbon isotope analyses -- identify energy pathways. Cell counts, ATP concentration, respiration rates, uptake of labeled substances. Water and soil buffer capacity. Complexation. Redox potential. Ion exchange capacity. Adsorption capacity. Dissolution/precipitation rates. Decomposition rates. Plant growth rates, biomass production.
Maintain landscape pathways	➢ Maintains longitudinal and latitudinal connectivity to allow for biotic and abiotic energy process pathways. ➢ Serves as barriers, corridors, or buffers to plant and animal migration. ➢ Provides source and sink areas for maintaining population equilibrium of plant and animal species.	Presence of animal trails along corridor. Observations of migratory species use. Flood tolerance of vegetation species on floodplains. Presence/absence of key indicator species in portions of the adjacent landscape. Recent deposits of sediments and detrital matter in the riparian corridor. Distribution, density, diversity, and age class composition of riparian vegetation. Accumulation of species during high stress periods.	Relative scale of stream to riparian corridor as a function of stream order or slope. Width, density, and composition of riparian vegetation community. Frequency and duration of floodplain inundation. Migratory bird surveys. Measures of sediment deposition and detrital flux in the riparian corridor. Migration barrier surveys. Genetic analyses. Canopy cover measurements of various life forms. Temperature.

Table 7. Example Relations Between Beneficial Uses and Functions.

Beneficial Uses	Function				
	System Dynamics	Hydrologic Balance	Sediment Processes and Character	Biological Support	Chemical Processes and Pathways
Sink					
Cooling water	**O**	**O**	**O**	**I**	**I/O**
Drainage	**O**	**I/O**	**I/O**	**I**	**I/O**
Flood storage / attenuation	**I/O**	**I/O**	**I/O**	**I/O**	**I/O**
Wastewater	**O**	**O**	**O**	**I**	**I**
Consumptive					
Aggregate withdrawal	**I/O**	**I/O**	**I/O**	**I/O**	**I/O**
Drinking water	**O**	**I/O**	**O**	**I/O**	**I/O**
Fishing and hunting	**O**	**O**	**O**	**I/O**	**I/O**
Hydropower	**I/O**	**I/O**	**I/O**	**I/O**	**I**
Industrial water supply	**I/O**	**I/O**	**I/O**	**I**	**I/O**
Irrigation	**I/O**	**I/O**	**I/O**	**I**	**I/O**
Groundwater withdrawal	**-**	**I/O**	**-**	**I**	**I/O**
Riparian timber harvest	**I/O**	**I/O**	**I/O**	**I/O**	**I**
Non-consumptive					
Aesthetics	**O**	**-**	**O**	**-**	**-**
Ecosystem protection	**I/O**	**I/O**	**I/O**	**I/O**	**I/O**
Housing	**I/O**	**I/O**	**I/O**	**I**	**I**
Landscape feature	**O**	**-**	**O**	**I**	**I**
Recreational boating	**I/O**	**O**	**O**	**I/O**	**I/O**
Commercial transport	**I/O**	**I/O**	**I/O**	**I/O**	**I/O**
Navigation service	**I/O**	**O**	**I/O**	**I/O**	**I**
Non-boating recreation	**O**	**O**	**O**	**I/O**	**I/O**
Spatial corridor	**I/O**	**I/O**	**I/O**	**I/O**	**I/O**

Key:
- \- No discernible impact.
- I Use may impact indicated function.
- O Use may be impacted by indicated function.

Table 8. Hierarchy of Functions.

Rank	Function	Functions Directly Affected[1]	Functions Indirectly Affected[1]
1	Hydrodynamic Character	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	13
2	Stream Evolution Processes	1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	9, 13
3	Surface Water Storage Processes	1, 4, 6, 10, 11, 12, 14, 15	2, 5, 7, 8, 9, 13
4	Sediment Continuity	3, 5, 6, 7, 8, 9, 11, 15	1, 13, 14
5	Riparian Succession	1, 2, 3, 4, 6, 12, 14, 15	9, 13
6	Energy Management	1, 2, 3, 4, 5, 7, 8, 15	-
7	Substrate and Structural Processes	1, 2, 4, 6, 7, 10, 15	5, 9, 11, 13
8	Quality and Quantity of Sediments	2, 4, 5, 6, 7, 10, 15	1, 9, 11, 14
9	Biological Communities and Processes	5, 11, 13, 14, 15	1, 2, 3, 7, 8, 10, 12
10	Surface / Subsurface Water Exchange	1, 5, 11, 15	3, 9, 12, 13
11	Water and Soil Quality	8, 9, 13, 14	5
12	Landscape Pathways	9, 13, 14, 15	6
13	Trophic Structures and Processes	9, 11, 14	8
14	Chemical Processes and Nutrient Cycles	8, 9, 13	6
15	Necessary Habitats for all Life Cycles	9, 12, 13	-

[1] Listed by number, according to ranking (e.g. Function #6 is Energy Management)
Note: The interactions among functions are such that the relations presented in Table 8 can change with the type of ecosystem, and the nature and magnitude of the impact, and the specific temporal and spatial scales utilized in the relevant analysis. This is particularly true for the indirect impacts.

SUMMARY

Quality stream ecosystems have healthy watersheds, wide and relatively continuous riparian areas, active floodplains, suitable channel dimensions for the prevailing conditions, and an appropriate level of diversity and dynamics. Unfortunately, most of the streams in the United States do not benefit from all of these conditions. Anthropogenic activities have significantly degraded many stream and riparian systems.

Efforts to restore these degraded systems, while well-intentioned, are often inappropriate or ineffective because they fail to address the underlying processes that create and maintain the elements listed above. Most conventional stream restoration projects are highly engineered efforts to stabilize streams while concurrently improving habitat for adult life stages of a few species – often to the detriment of native flora and fauna and to the sustainability of the system.

Most resource professionals understand intuitively that ecosystems consist of many linkages and, to fully comprehend the impacts of ecosystem alterations, these linkages must be understood.

This document identifies a suite of 15 functions that are critical to the sustenance of stream and riparian ecosystems. These functions can help planners and designers form an understanding of the cause/effect relationships that dictate system response to change and, thus, serve as a basis to formulate alternatives and assess project impacts and benefits in a manner consistent with the Corps' Environmental Operating Principles.

ACKNOWLEDGEMENTS

Research presented in this technical note was developed under the U.S. Army Corps of Engineers Ecosystem Management and Restoration Research Program. This report was prepared by Dr. Craig Fischenich, U.S. Army Engineer Research and Development Center, Environmental Laboratory. The assistance of many contributors is gratefully acknowledged. Dr. Bruce Pruitt, U.S. EPA Region 4, and Mr. Brian Riggers, U.S. Forest Service, Lolo National Forest, played a central

role in the development of the general basis for the functional framework. Establishment of the key functions was aided by an International committee of scientists including: Mr. Jos Van Alphen, Rijkswaterstaat directie Oost-Nederland; Mr. Georg Rast, World Wildlife Fund, Germany; Capt. Heather Mitchell, Mitchell Associates, UK; Prof. J.M. Hiver, Laboratoire de Recherches Hydraulique, Belgium; Dr. Michael Fiedler, Federal Institute of Hydrology, Germany; Mr. Paul Pierron, Mission d'Inspection Generale territoriale, France; Mr. Jan Reche, Federal Ministry of Transport, Building and Housing, Germany; Mr. Enrique Uribarri, Alatec Proes S.A, Spain; Dr. Richard Hey, East Anglia University, UK; and Dr. Jack Imhof, Ontario Ministry of Natural Resources. Many practitioners assisted in the assessment of the recommendations, and their assistance is gratefully acknowledged. Technical reviews were provided by Dr. Richard Fischer and Messrs. Jim Henderson and Jock Conyngham, of the Environmental Laboratory.

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> Fischenich, J.C. (2006). Functional objectives for stream restoration. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-52). Vicksburg, MS: U.S. Army Engineer Research and Development Center. *www.wes.army.mil/el/emrrp*

ANNOTATED REFERENCES AND BIBLIOGRAPHY

Abbe, T.B., Mongomery, D.R., and Petroff, C. (1997) "Design of stable in-channel wood debris structures for bank protection and habitat restoration: An example from the Cowlitz River, WA," Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 809-814.
Most bank protection structures not designed to improve aquatic or riparian habitat and restoration projects lack sufficient engineering and geomorphic analysis. This project demonstrated that engineered log jams can meet erosion control objectives while restoring riverine habitat in large alluvial rivers. There is good potential for integrating natural processes into river engineering in ways that will meet human objectives for limiting bank erosion while maintaining habitat.

Benke, S.C., Henry, R.L., III, Gillespie, D.M., and Hunter, R.J. (1985) "Importance of snag habitat for animal production in southeastern streams," *Fisheries*, 10-5, 8-13.
This study showed that snagging operations, as performed by many agencies over the years in order to enhance navigation or modify channels, can devastate much of the fish community. Furthermore, removal of the snags can increase water velocity, adversely affect stream channels and riparian vegetation, reduce the frequency of floodplain inundation, and alter nutrient and organic matter pathways.

Beschta, R.L., and Platts, W.S. (1986) "Morphological features of small streams: Significance and function," *Water Resources Bulletin*, 22-3, 369-379.
Where channel morphology is modified or structural features are added, stream dynamics and energy dissipation need to be considered. Understanding each stream feature individually and in relation to all others is essential for proper stream management. Although engineered structures for modifying habitat may alter stream characteristics, channel morphology must ultimately be matched to the hydraulic, geologic, and [especially] vegetative constraints of a particular location.

Bravard, J.P., Amoros, C. and Patou, G. (1985) "Impact of civil engineering works on the successions of communities in a fluvial system," *Oikos*, 47-1, 92-111.
Fluvial dynamics determine the habitat diversity by the erosion-deposition processes that create biotopes. Contemporary impacts, such as navigational embankments, hydroelectric projects, and the protection of agricultural land halt the fluvial dynamics by restricting the extension of the area of active geomorphology. The absence of lateral erosion prevents the initiation of succession and leads to the disappearance of communities corresponding to the first stages of the sequence.

Brinson, M. M. (1993). "A hydrogeomorphic classification for wetlands," Technical Report WRPDE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
An overview of the HGM classification and the basis for its use.

Brinson, M. M., Hauer, F. R., Lee, L. C., Nutter, W. L., Rheinhardt, R. D., Smith, R. D., and Whigham, D. (1995) "A guidebook for application of hydrogeomorphic assessments to riverine wetlands," Wetlands Research Program Technical Report WRP-DE-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
Provides details of the application of HGM to riverine wetlands.

Burke, T. D., and Robinson, J. W. (1979) River structure modifications to provide habitat diversity," A National Workshop on Mitigating Losses of Fish and Wildlife Habitats, General Technical Report RM-65, Colorado State University, pp. 556-561.
Discussion of beneficial and detrimental effects of Missouri River Bank Stabilization and Navigation Project and description of structure modifications used to improve fish and wildlife habitats, flood carrying capacity, and for controlling accretions. Methods include notched, rootless, and low elevation structures.

Downs, P.W., and Thorne, C.R. (2000) "Rehabilitation of a lowland river: reconciling flood defense with habitat diversity and geomorphological sustainability," *J. of Environmental Management*, 58, 249-268.
The authors concluded that true restoration was neither possible nor desireable on the River Idle in the United Kingdom. Management objectives are geared towards environmental enhancement through rehabilitation. The requirement to reconcile environmental enhancement with the river's ongoing flood defense function remains a challenge, while the desire to produce a sustainable solution influences long-term planning.

Ehrenfield, J.G. (2000) "Defining the limits of restoration: The need for realistic goals," *Restoration Ecology*, 8-1, 2-9.
This paper describes the advantages and disadvantages of restoration project goals at three different levels: Species, ecosystem functions, and ecosystem services. It provides quantifiable components of selected ecosystem processes that are part of the ecosystem functions, and a list of various ecosystem services that have been proposed in recent publications.

Fischenich, J.C. (2001) "Impact of Streambank Stabilization Measures," EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-32), U.S. Army Engineer Research and Development Center, Vicksburg, MS.
Provides an overview of the impacts of various stream alteration and stabilization measures upon a wide range of riverine processes.

Fischenich, J.C. (2002). "Impacts of Riprap on Aquatic and Riparian Ecosystems," USACE Wetlands Regulatory Assistance Program, Technical Report ERDC-EL TR 03-04, Vicksburg, MS.
Discusses the influence of riprap on the lotic environment and provides guidelines for measures to reduce impacts.

Fleming, N.S., and Daniell, T.M. (1993) "Sustainable water resources management: An Australian perspective," Paper presented at the International Conf. On Environmentally Sound Water Resources Utilization, Bangkok, Thailand, 8-11 November, 1993.
Evidence is mounting that current methods of natural resource use and development are unsustainable, which impacts economic efficacy and causes serious environmental degradation. To achieve sustainability in water resources

requires a focus on the integrated use of land and water resources, with the aim of ensuring a high level of water quality; use of water within the sustainable yield of the resource; and maintenance of biological diversity.

Goldsmith, W., and Buchanan, D. (1999) "Practical bioengineering applications in watershed management," *Land and Water*, July/August, 1999, 11-15.
This is more of a philosophical paper, and contains no hard data or literature. However, it espouses the theory that our streams and rivers have suffered tremendous and largely unnecessary damage due to poor management and a lack of understanding of basic ecological principles. It also contains a table showing characteristics of healthy and impaired watersheds, and potential restoration objectives.

Gore, J. A., and Shields, F. D., Jr. (1995) "Can large rivers be restored," *BioScience*, 45-3, 142-152.
Although restoration of large rivers to a pristine condition is probably not practical, there is considerable potential for rehabilitation, that is, the partial restoration of riverine habitats and ecosystems. Renewal of physical and biological interactions between the main channel, backwaters, and floodplains is central to the rehabilitation of large rivers.

Gorman, O. T., and Karr, J. R. (1978) "Habitat structure and stream fish communities," *Ecology*, 59-3, 507-515.
Increasing community and habitat diversity followed stream-order gradients. Natural streams supported fish communities of high species diversity, which were seasonally more stable than the lower-diversity communities of modified streams. After disturbances such as channelization, seasonal peaks in species diversity attain levels typical of undisturbed streams.

Griggs, G.B., and Paris, L. (1982) "Flood control failure: San Lorenzo River, California," *Environmental Management*, 6-5, 407-419.
The problem of flooding cannot simply be resolved by engineering. Large flood control projects provide a false sense of security and commonly produce unexpected channel changes. Any engineering protection is both limited and temporary. In the case of the San Lorenzo River project, the channel was excavated below the natural grade and levees were constructed to contain the 100-year flood. The natural response of the river to return to its equilibrium condition resulted in significant sedimentation and reduction in flood control capability.

Gwin, S.E., Kentula, M.E., and Shaffer, P.W. (1999) "Evaluating the effects of wetland regulation through hydrogeomorphic classification and landscape profiles," *Wetlands*, 19-3, 477-489.
Landscape profiles describing the pattern of diversity of wetlands in a region can serve as a standard for characterizing the resource and quantifying the effects of management decisions. The authors used HGM classification to generate landscape profiles to evaluate the effects of mitigation in the Portland, OR area.

Hauer, F.R., and Smith, R.D. (1998) "The hydrogeomorphic approach to functional assessment of riparian wetlands: Evaluating impacts and mitigation on river floodplains in the U.S.A.," *Freshwater Biology*, 40,517-530.
The authors describe the development of the HGM approach and potential applications for protecting and monitoring riparian wetlands. Assessment models for 14 alluvial wetlands functions are described.

Heede, B.H. (1986) "Designing for dynamic equilibrium in streams," *Water Resources Bulletin*, 22-3, 351-357.
Streams are dynamic systems, so steady state does not exist for any appreciable period of time. Meanders and degradation/aggradation of the bed are adjustment processes of the stream. If humans interfere with the processes, other adjustment processes will be initiated. However, by working with ongoing processes, success is attainable with less effort and lower cost.

Henderson, J. E. (1986) "Environmental designs for stream bank protection projects," *Water Resources Bulletin*, 22-4, 549-558.
Adverse environmental impacts have been minimized and existing habitat and aesthetics have been enhanced through the development of new, innovative designs or modifications to existing designs and through use of construction and maintenance practices that promote habitat

and aesthetics. Vegetation for bank protection is most effective when used in combination with structural components.

Hickey, J.T., and Diaz, G.E. (1999) "From flow to fish to dollars: An integrated approach to water allocation," *J. of the American Water Resources Association*, 35-5, 1053-1067.
This paper presents the results of a case study on the value and application of a conceptual integration of economic, salmonid population, physical habitat, and water allocation models.

Hill, M.T., Platts, W.S., and Beschta, R.L. (1991) "Ecological and geomorphological concepts for instream and out-of-channel flow requirements," *Rivers*, 2-3, 198-210.
Alteration of streamflow for power production, irrigation, flood control, and other purposes adversely affects aquatic resources. The authors examined various concepts concerning the broad interactions of fluvial-geomorphic processes, riverine-riparian habitat, and their geographic setting.

Hobbs, R.J., and Norton, D.A. (1996) "Towards a conceptual framework for restoration ecology," *Restoration Ecology*, 4-2, 93-110.
Key processes in restoration include identifying and dealing with the processes leading to degradation in the first place, determining realistic goals and measures of success, developing methods for implementing the goals and incorporating them into land management and planning strategies, and monitoring the restoration and assessing its success. To become a useful tool, restoration ecology must become a landscape-scale endeavor.

Johnson, B.L., Richardson, W.B., and Naimo, T.J. (1995) "Past, present, and future concepts in large river ecology," *Bioscience*, 45-3, 134-141.
Despite the importance of large rivers, understanding how they function and how human activities influence river processes is limited. There are currently two primary hypotheses of how lotic systems function: the river continuum concept with its corollaries and the flood-pulse concept. Neither of these explains system function in all large rivers.

Klingeman, P. C. (1984) "Evaluating hydrologic needs for design of stream habitat modification structures," *Proceedings of the Pacific Northwest Stream Habitat Workshop, Arcata, CA.*
This paper describes the needs and uses of basic hydrologic, hydraulic, and geomorphic information for designing a stream habitat modification structure at a site. Also, common types of stream habitat modification structures are described.

Kondolf, G.M. (2000) "Some suggested guidelines for geomorphic aspects of anadromous salmonid habitat restoration proposals," *Restoration Ecology*, 8-1, 48-56.
To be successful, river restoration projects must account for geomorphic processes at both the watershed and reach scales. In streams with sufficient energy and sediment load to recreate a natural channel morphology during floods, aquatic habitat might best be served by no direct physical intervention beyond removing those factors that negatively influence habitat [e.g., close levees, riprap banks, etc.].

Montgomery, D.R. (1995) "Input- and output-oriented approaches to implementing ecosystem management," *Environmental Management*, 19-2, 183-188.
Input-oriented landscape management provides the foundation for implementing ecosystem management based on current knowledge of processes and linkages among biological and physical components of an ecosystem and the influences of human actions on those processes and linkages. Defining the priorities between resource use or extraction and acceptable changes in ecosystem condition is a component of any land management framework.

Moyle, P.B., and Randall, P.J. (1998) "Evaluating the biotic integrity of watersheds in the Sierra Nevada, California," *Conservation Biology*, 12-6, 1318-1326.
The authors contend that one problem with the selected watershed approach to conservation is that it implies that watersheds can be systematically rated so that those with the highest biodiversity values can be the focus of whole-watershed protection efforts. They present an alternated method, called the watershed index of biotic integrity [W-IBI], for

identifying watersheds with high conservation potential over a much larger area.

Naiman, R.J., Bilby, R.E., and Bisson, P.A. (2000) “Riparian ecology and management in the Pacific coastal rain forest,” *Bioscience*, 50-11, 996-1011.
This paper discusses the role of the many dynamic processes affecting riparian zones within the Pacific coastal rain forest. Dramatic changes in the management of riparian areas have been driven by new understandings of riparian processes. These new insights include: restoring biophysical properties of riparian zones improves all natural resource values; protecting interactions between surface flows and groundwater is essential to aquatic-riparian integrity; allowing streams and rivers to migrate laterally is necessary for habitat development; incorporating natural flow regime characteristics in regulated rivers promotes aquatic and riparian diversity and resilience; and control of exotic species depends on reestablishing natural land-water interactions in riparian areas.

National Research Council. (1996) Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. Committee on Restoration of Aquatic Ecosystems — Science, Technology, and Public Policy, Water Science and Technology Board, Commission on Geosciences, Environment, and Resources, National Research Council. — Washington, DC.
Presents an overview of the state of science, state of practice, and case studies for restoration.

Newbury, R., and Gaboury, M. (1993) “Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour,” *Freshwater Biology*, 29, 195-210.
Rivers and streams are integrated flowing systems that create and maintain aquatic habitats within the structure of their flow as well as on and below their wetted boundaries. The combination of elements from geomorphology, open-channel hydraulics, and hydraulic habitat requirements of stream fish form the basis for an ecologically sound “soft engineering” of river channels. Two project examples were used to demonstrate how this “soft engineering” approach enhanced the fish habitat.

Pastorok, R. A., MacDonald, A., Sampson, J. R., Wilber, P., Yozzo, D. J., and Titre, J. P. (1997) “An ecological decision framework for environmental restoration projects,” *Ecological Engineering*, 9, 89-107.
Ecosystem restoration projects require planning and monitoring, yet projects completed thus far have been planned on an ad hoc, consensus basis and are virtually ignored after revegetation at the site is complete. A process was developed to integrate a fundamental understanding of ecological principles into the existing project planning framework used by the U. S. Army Corps of Engineers in their growing role in restoration of aquatic habitats, but it should be applied to terrestrial habitats as well.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., and Stromberg, J.C. (1997) “The natural flow regime,” *Bioscience*, 47-11, 769-784.
Historically, the protection of river ecosystems has been limited in scope, emphasizing water quality and only one aspect of water quantity: minimum flow. Five critical components of the flow regime regulate ecological processes in river ecosystems: the magnitude, frequency, duration, timing, and rate of change of hydrologic conditions. By defining flow regimes in these terms, the ecological consequences of particular human activities that modify one or more components of the flow regime can be considered explicitly. To manage rivers from this new perspective, some policy changes are needed with regard to narrow regulatory focus and conflicting mandates of multiple agencies.

Prichard, D. (1998) *Riparian Area Management*, Technical Reference 1737-15, USDI Bureau of Land Management, National Applied Resource Sciences Center, Denver, CO.
This report describes a methodology for determining the Proper Functioning Condition [PFC] for riparian-wetland areas. Various functions and processes that the wetland should be able to address are used to determine the condition of the area.

Reiman, B.E., Lee, D.C., Thurow, R.F., Hessburg, P.F., and Sedell, J.R. (2000) "Toward an integrated classification of ecosystems: defining opportunities for managing fish and forest health," *Environmental Management*, 25-4, 425-444.
The goals of aquatic and terrestrial conservation and restoration are often viewed as being in conflict. The authors used recent information on forest and fish communities to classify river sub-basins across the region and explore the potential conflict and opportunity for a more integrated view of management. The classification indicated that there are often common trends in terrestrial and aquatic communities that highlight areas of potential convergence in management goals.

Rosgen, D. L. (1997) "A geomorphological approach to restoration of incised rivers," *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*, 12-29.
Geomorphologic concepts are described as integrated into incised river restoration projects. A range of restoration design concepts are presented including; returning the stream to its original elevation and re-connecting floodplains, widening the belt width to construct a new channel at the existing elevation, changing stream types, and stabilizing the existing incised channel in place.

Shaffer, P.W., Kentula, M.E., and Gwin, S.E. (1999) "Characterization of wetland hydrology using hydrogeomorphic classification," *Wetlands*, 19-3, 490-504.
Because hydrology is an important determinant of many wetland functions, resource managers using restoration and mitigation to offset wetland losses should strive for project design and siting that re-establish the hydrogeomorphology of natural wetlands to improve the likelihood of replacing wetland functions. This study provided a test of HGM classification as a tool for characterizing wetlands in a geographic region in which HGM has not been previously applied. Results suggest the potential to use the classification to generalize results from a relatively small sample to the larger population of wetlands within the landscape.

Shields, F. D., Jr., and Hoover, J. J. (1991) "Effects of channel restabilization on habitat diversity, Twentymile Creek, Mississippi," *Regulated Rivers: Research & Management*, 6, 163-181.
Twentymile Creek was channelized prior to 1910, in 1938, and in 1966. Straightening and enlargement in 1966 resulted in channel instability, rapid bed degradation and cross-section enlargement. Grade control structures and various types of streambank protection were constructed along the channel in the early 80's to restore stability. This paper studies the effects of restabilization of Twentymile Creek on aquatic habitats.

Shields, F. D., Jr., Knight, S. S., and Cooper, C. M. (1998) "Rehabilitation of aquatic habitats in warmwater streams damaged by channel incision in Mississippi," *Hydrobiologia* 382, 63-86.
A study of incised warmwater stream rehabilitation was conducted to develop and demonstrate techniques that would be economically feasible for integration with more orthodox, extensively employed watershed stabilization techniques. During the study two reaches were modified by adding woody vegetation and stone structure to rehabilitate habitats degraded by erosion and channelization. These experiments suggest that major gains in stream ecosystem rehabilitation can be made through relatively modest but well-designed efforts to modify degraded physical habitats.

Shields, F.D., Jr., and Smith, R.H. (1992) "Effects of large woody debris removal on physical characteristics of a sand-bed river," *Aquatic Conservation: Marine and Freshwater Ecosystems*, 2, 145-163.
Results suggest that benefits of proposed LWD removal projects should be carefully analyzed in the light of costs and environmental impacts. Removal of LWD in the study reaches decreased the friction factor for near-bankful conditions by about one third and increased bankful flow capacity by about one fourth. Erosion triggered by LWD removal may increase channel maintenance costs.

Sparks, R.E., (1995) "Need for ecosystem management of large rivers and their floodplains," *Bioscience*, 45-3, 168-182.
The author describes the importance of large river-floodplain ecosystems and the consequences of altering their natural processes, functions, and connectivity.

United Nations. (1992) Agenda 21, the *Rio Declaration on Environment and Development*, and the *Statement of principles for the Sustainable Management of Forests* were adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janerio, Brazil, 3-14 June 1992.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E. (1980) "The river continuum concept," *Canadian Journal of Fisheries and Aquatic Science*, 37,130-137.
Physical variables within a river system present a continuous gradient of physical conditions. The river continuum concept provides a framework for integrating predictable and observable biological features of the lotic systems. Although the model was developed specifically in reference to natural, unperturbed stream ecosystems, it should accommodate many unnatural disturbances, as well.

Wesche, T. A., (1985) "Stream channel modifications and reclamation structures to enhance fish habitat," *The Restoration of Rivers and Streams*, Chapter 5, Butterworth Publishers.
Many of the detrimental effects of channelization can be avoided, with little compromise in channel efficiency, by employing channel design guidelines that do not destroy the hydraulic and morphologic equilibrium that natural streams possess. These guidelines include minimal straightening; promoting bank stability by leaving trees, minimizing channel reshaping, and employing bank stabilization techniques; and, emulating the morphology of natural stream channels.

Wissmar, R.C., and Beschta, R.L. (1998) "Restoration and management of riparian ecosystems: a catchment perspective," *Freshwater Biology*, 40, 571-585.
This paper examines approaches and perspectives for restoration of riparian ecosystems. Sound restoration strategies require an understanding of the processes, functional attributes, and the landscape connectivity of riverine habitats, both temporally and spatially. The process of developing a restoration strategy also requires an understanding of the influences of present-day human land and water uses and management practices.